PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Assistant Commissioner for Patents
United States Patent and Trademark Office
Box PCT
Washington, D.C.20231
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 18 May 2000 (18.05.00)	
International application No. PCT/US99/16477	**Applicant's or agent's file reference** GDC-128 PCT
International filing date (day/month/year) 21 July 1999 (21.07.99)	**Priority date** (day/month/year) 22 July 1998 (22.07.98)
Applicant HUSSAIN, Iftekhar et al	

1. The designated Office is hereby notified of its election made:

[X] in the demand filed with the International Preliminary Examining Authority on:

18 January 2000 (18.01.00)

[ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was

[ ] was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

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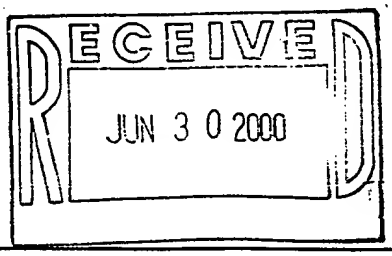
PATENT COOPERATION TREATY

From the
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

To: DAVID P. GORDON
65 WOODS END ROAD
STAMFORD, CT 06905



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NOTIFICATION OF TRANSMITTAL OF INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Rule 71.1)

Applicant's or agent's file reference GDC-128 PCT	Date of Mailing *(day/month/year)* 28 JUN 2000 **IMPORTANT NOTIFICATION**

International application No.	International filing date *(day/month/year)*	Priority Date *(day/month/year)*
PCT/US99/16477	21 JULY 1999	22 JULY 1998

Applicant
GENERAL DATACOMM, INC.

1. The applicant is hereby notified that this International Preliminary Examining Authority transmits herewith the international preliminary examination report and its annexes, if any, established on the international application.

2. A copy of the report and its annexes, if any, is being transmitted to the International Bureau for communication to all the elected Offices.

3. Where required by any of the elected Offices, the International Bureau will prepare an English translation of the report (but not of any annexes) and will transmit such translation to those Offices.

4. REMINDER

The applicant must enter the national phase before each elected Office by performing certain acts (filing translations and paying national fees) within 30 months from the priority date (or later in some Offices)(Article 39(1))(see also the reminder sent by the International Bureau with Form PCT/IB/301).

Where a translation of the international application must be furnished to an elected Office, that translation must contain a translation of any annexes to the international preliminary examination report. It is the applicant's responsibility to prepare and furnish such translation directly to each elected Office concerned.

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Name and mailing address of the IPEA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	THOMAS C. LEE For Regina Gogan
Facsimile No. (703) 305-3230	Telephone No. (703) 305-3804

Form PCT/IPEA/416 (July 1992) ★

PATENT COOPERATION TREATY

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(PCT Rule 71.1)

Date of Mailing *(day/month/year)*	28 JUN 2000

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GDC-128 PCT	

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Facsimile No. (703) 305-3230	Telephone No. (703) 305-3804

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PATENT COOPERATION TREATY

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INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference GDC-128 PCT	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/US99/16477	International filing date *(day/month/year)* 21 JULY 1999	Priority date *(day/month/year)* 22 JULY 1998
International Patent Classification (IPC) or national classification and IPC IPC(7): G06F 13/14 and US Cl.: 370/17, 60.1, 61, 232, 253		
Applicant GENERAL DATACOMM, INC.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 3 sheets.

   ☐ This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority. (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 0 sheets.

3. This report contains indications relating to the following items:

   I ☒ Basis of the report

   II ☐ Priority

   III ☐ Non-establishment of report with regard to novelty, inventive step or industrial applicability

   IV ☐ Lack of unity of invention

   V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

   VI ☐ Certain documents cited

   VII ☐ Certain defects in the international application

   VIII ☐ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
18 JANUARY 2000	21 MAY 2000
Name and mailing address of the IPEA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer THOMAS C. LEE For Eugenia Zagorin Telephone No. (703) 305-3804

Form PCT/IPEA/409 (cover sheet) (July 1998) ★

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.
PCT/US99/16477

I. Basis of the report

1. With regard to the **elements** of the international application:*

[X] the international application as originally filed

[X] the description:
pages 1-12 , as originally filed
pages NONE , filed with the demand
pages NONE , filed with the letter of _____

[X] the claims:
pages 13-16 , as originally filed
pages NONE , as amended (together with any statement) under Article 19
pages NONE , filed with the demand
pages NONE , filed with the letter of _____

[X] the drawings:
pages 1 , as originally filed
pages NONE , filed with the demand
pages NONE , filed with the letter of _____

[X] the sequence listing part of the description:
pages NONE , as originally filed
pages NONE , filed with the demand
pages NONE , filed with the letter of _____

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These elements were available or furnished to this Authority in the following language _____ which is:

[ ] the language of a translation furnished for the purposes of international search (under Rule 23.1(b)).

[ ] the language of publication of the international application (under Rule 48.3(b)).

[ ] the language of the translation furnished for the purposes of international preliminary examination (under Rules 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

[ ] contained in the international application in printed form.

[ ] filed together with the international application in computer readable form.

[ ] furnished subsequently to this Authority in written form.

[ ] furnished subsequently to this Authority in computer readable form.

[ ] The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

[ ] The statement that the information recorded in computer readable form is identical to the writen sequence listing has been furnished.

4. [X] The amendments have resulted in the cancellation of:

[X] the description, pages NONE

[X] the claims, Nos. NONE

[X] the drawings, sheets/~~fig~~ NONE

5. [ ] This report has been drawn as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).**

** Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17).*

***Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.*

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. statement

Novelty (N)	Claims	1-16	YES
	Claims	NONE	NO
Inventive Step (IS)	Claims	1-16	YES
	Claims	NONE	NO
Industrial Applicability (IA)	Claims	1-16	YES
	Claims	NONE	NO

2. citations and explanations (Rule 70.7)

Claims 1-16 meet the criteria set out in PCT Article 33(2)-(4), because US 5,541,912 (Choudhury et al) does not teach or fairly suggest setting a minimum queue threshold for each queue at the time it is created based on the service category of the virtual connection for which the que was created; dynamically adjusting the queue threshold for each queue based on the minimum queue threshold and the amount of unused shared buffer space.

---------- NEW CITATIONS ----------

NONE

PATENT COOPERATION TREATY

PCT

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INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference GDC-128 PCT	**FOR FURTHER ACTION**	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/US99/16477	International filing date *(day/month/year)* 21 JULY 1999	Priority date *(day/month/year)* 22 JULY 1998
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Name and mailing address of the IPEA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer THOMAS C. LEE For Telephone No. (703) 305-3804

Form PCT/IPEA/409 (cover sheet) (July 1998) ★

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International application No.
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INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.
PCT/US99/16477

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

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Novelty (N)	Claims	1-16	YES
	Claims	NONE	NO
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	Claims	NONE	NO
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Claims 1-16 meet the criteria set out in PCT Article 33(2)-(4), because US 5,541,912 (Choudhury et al) does not teach or fairly suggest setting a minimum queue threshold for each queue at the time it is created based on the service category of the virtual connection for which the que was created; dynamically adjusting the queue threshold for each queue based on the minimum queue threshold and the amount of unused shared buffer space.

---------- NEW CITATIONS ----------

NONE

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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 :
G06F 13/14

A1

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(43) International Publication Date: 3 February 2000 (03.02.00)

(21) International Application Number: PCT/US99/16477

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(30) Priority Data:
60/093,681 22 July 1998 (22.07.98) US

(71) Applicant *(for all designated States except US)*: GENERAL DATACOMM, INC. [US/US]; 1579 Straits Turnpike, P.O. Box 1299, Middlebury, CT 06762–1299 (US).

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(74) Agent: GORDON, David, P.; 65 Woods End Road, Stamford, CT 06905 (US).

(81) Designated States: CA, JP, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

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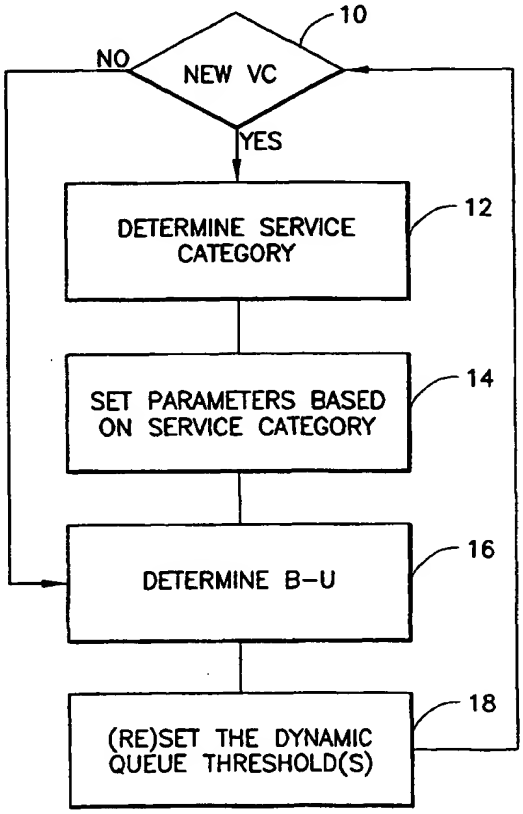
(54) Title: DYNAMIC BUFFER MANAGEMENT SCHEME FOR ATM SWITCHES

(57) Abstract

A buffer management scheme for a shared memory in an ATM switch sets different dynamic thresholds (18) for different Vcs (10) according to the formula: Tsub i (U) = Tsub Fsub i + gama sub i . (B – U) where B is the total size of the shared buffer and U is the size of the used portion of the buffer. According to the invention, Tsub i (U) is the threshold (in number of cells) for the ith connection when the used portion of the buffer is U, Tsub Fsub i is the required buffer allocation (in number of cells) for the ith connection buffer when the buffer is full and gama sub i is a power of two chosen for the ith connection at the time the connection is set–up. Both Tsub Fsub i and gama sub i are chosen based on the service category of the connection (12). In addition, the buffer management scheme sets minimum and maximum buffer sizes based on the service category of the connection. Preferably, a minimum buffer is guaranteed for service categories above UBR (unspecified bit rate). For UBR traffic, the minimum buffer available is determined by the number of backlogged connections. The maximum buffer size for each connection is a function of the total buffer size B, Tsub Fsub i and gama sub i.



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DYNAMIC BUFFER MANAGEMENT SCHEME FOR ATM SWITCHES

This application claims the benefit of provisional application Serial Number 60/093,681 filed July 22, 1998.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates broadly to the field of telecommunications. More particularly, the present invention relates to the management of shared memory buffers in an asynchronous transfer mode (ATM) switch or node by setting of queue size and dynamic queue thresholds as functions of overall buffer occupancy and service category.

2. State of the Art

Perhaps the most awaited, and now fastest growing technology in the field of telecommunications in the 1990's is known as Asynchronous Transfer Mode (ATM) technology. ATM is providing a mechanism for removing performance limitations of local area networks (LANs) and wide area networks (WANs) and providing data transfers at a speed of on the order of gigabits/second. The variable length packets of LAN and WAN data are being replaced with ATM cells which are relatively short, fixed length packets. Because ATM cells can carry voice, video and data across a single backbone network, the ATM technology provides a unitary mechanism for high speed end-to-end telecommunications traffic.

Because the data contained in the ATM cells can be generated from either generally fixed rate communications, or bursty type communications, it will be appreciated that traffic accommodation mechanisms have been introduced in order to avoid situations where ATM switches or nodes are over-taxed, resulting in loss of cells. In particular, various buffering mechanisms are well known. Among these include input queues, output queues, and shared buffers. It is now generally agreed that

shared buffers are the preferred mechanism for implementing either input queues or output queues (or both) in an ATM switch.

The simplest implementation of shared memory buffers sets up queues for virtual connections (VCs) as needed and sets a queue length threshold for each queue regardless of the service category of the VC. This implementation is often referred to as the "Static Threshold" scheme. Arriving cells are admitted to the queue only if the queue length is smaller than the threshold set for the queue. Although the Static Threshold scheme is simple to implement, it does not adapt to changing traffic conditions. If one port in the switch (one VC) is very active, cells from that VC will be lost even if there is shared memory available to enlarge the queue.

Several "Dynamic Threshold" schemes have been proposed. These schemes attempt to adjust the queue length thresholds of all of the queues in shared memory based on the amount of currently available memory. One scheme for dynamic buffer management is disclosed in A. K. Choudhury and E. L. Hahne, Dynamic Queue Length Thresholds in a Shared Memory ATM Switch, Proc. IEEE INFOCOM '96 (San Francisco, California) pp. 1-9, March 1996 (hereinafter "Choudhury"). According to Choudhury, a control threshold $T(t)$ at time t is set (using notation of the present invention) equal to a multiple γ of the unused buffer space as shown in equation (1) where B is the total size of the shared buffer and U is the size of the used portion of the buffer.

$$T(t) = \gamma \cdot (B - U) \tag{1}$$

If any queue reaches a length greater than or equal to the control threshold $T(t)$, cells destined for that queue will be discarded. Choudhury states that γ should be a positive, negative, or zero power of two so that a shifter can be used to regulate the control threshold. According to Choudhury, γ is adjusted depending on whether the switch is moderately loaded or

heavily loaded and whether the load is uniform across all ports or non-uniform with one port more heavily loaded than others.

The Dynamic Threshold scheme of Choudhury is essentially a Static Threshold Scheme which is dynamically tuned according to load conditions in the switch. All VCs are treated equally and a certain amount of buffer space is intentionally wasted to accomplish this. The Choudhury scheme excels when there is a uniform load on the switch but does not provide much improvement over Static Threshold schemes when only a few ports in the switch are overloaded. Also, as specifically noted by Choudhury, the scheme does not address the issue of multiple service categories.

Current ATM service is offered in different categories according to a user's needs. Some of these categories include constant bit rate (CBR), variable bit rate (VBR), unspecified bit rate (UBR), and available bit rate (ABR). Some categories are given a higher priority than others when decisions are made to discard cells. For example, it is desirable that cells rarely, if ever, be discarded from CBR traffic. It has been recognized that the category of service should be taken into account when managing queues in shared memory. However, no scheme has been proposed for doing so.

SUMMARY OF THE INVENTION

It is therefore an object of the invention to provide a dynamic buffer management scheme for ATM switches.

It is also an object of the invention to provide a dynamic buffer management scheme which allocates shared buffer memory to VC queues based in part on the service category of the VC.

It is another object of the invention to provide a dynamic buffer management scheme which adjusts the allocation of shared

buffer memory to VC queues based in part on the service category of the VC and overall congestion in the ATM switch.

In accord with these objects which will be discussed in detail below, the buffer management scheme of the present invention sets different dynamic thresholds for different VCs according to the formula expressed in equation (2).

$$T_i(U) = T_{F_i} + \gamma_i \cdot (B - U) \qquad (2)$$

As in equation (1), B is the total size of the shared buffer and U is the size of the used portion of the buffer. According to the invention, $T_i(U)$ is the threshold (in number of cells) for the i^{th} connection when the used portion of the buffer is U. T_{Fi} is the minimum required buffer threshold allocation (in number of cells) for the i^{th} connection buffer when the buffer is full and γ_i is preferably a power of two chosen for the i^{th} connection at the time the connection is set-up. Both T_{Fi} and γ_i are chosen based on the service category of the connection.

In addition, the buffer management scheme of the present invention sets minimum and maximum buffer sizes based on the service category of the connection. Preferably, a minimum buffer is guaranteed for service categories above UBR (unspecified bit rate). For UBR traffic, the minimum buffer available is determined by the number of backlogged connections. The maximum buffer size for each connection is a function of the total buffer size B, T_{Fi}, and γ_i.

Additional objects and advantages of the invention will become apparent to those skilled in the art upon reference to the detailed description taken in conjunction with the provided figures.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a graph of the relationship between dynamic threshold and overall buffer occupancy; and

Figure 2 is a flow chart illustrating the operations of an apparatus according to the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

As mentioned above, a dynamic threshold $T(U)$ can be set such that if the number of cells Q_{VC} in a buffer equals or exceeds the threshold ($Q_{VC} \geq T(U)$), cells arriving at the buffer are discarded. Referring now to Figure 1, the dynamic threshold $T(U)$ is shown to be a linear function of the overall buffer occupancy U. In particular, it will be noted that as the overall buffer occupancy increases, the dynamic threshold decreases, i.e. cells will be discarded sooner. Thus, the linear function has a negative slope. The "y intercept" of the function, labelled "x" on the y-axis of Figure 1, is the integer value of the dynamic threshold when the overall buffer occupancy is empty. Thus, the minimum required buffer threshold allocation T_0 should be some integer number less than or equal to x. According to standard practices, buffer thresholds are set by add/subtract shift operations. Therefore, the slope of the function is preferably limited to an integer power of two, i.e. 2^y. The intercept and the slope of the function $T(U)$ can be chosen so that the threshold has some value T_F when the buffer is full as shown in equation (3).

$$T(B) = T_F = x - 2^y B \tag{3}$$

Thus, the value of the intercept x can be expressed as shown in equation (4).

$$x = T_F + 2^y B \tag{4}$$

As mentioned above, the threshold when the buffer is empty should be less than or equal to x as shown in equation (5).

$$x \geq T_0 \tag{5}$$

Substituting equation (4) for x in equation (5) yields equation (6).

$$T_F + 2^y B \geq T_0 \tag{6}$$

Equation (6) can be rewritten as equation (7).

$$2^y \geq \frac{T_0 - T_F}{B} \tag{7}$$

Therefore, an appropriate algorithm for choosing the value of y in order to set the slope of the threshold function can be expressed as equation (8).

$$y = \left\lceil \log_2 \left(\frac{T_0 - T_F}{B} \right) \right\rceil \tag{8}$$

According to one embodiment of the invention, equations (4) and (8) may be used directly at the time a VC is set up to determine x and y from B, T_0, and T_F. However, in the preferred embodiment y is selected on a per class basis, i.e. the value of y depends solely on the service category and the size of the buffer. T_F is also preferably based solely on the service category.

With the above considerations in mind, the buffer threshold formula according to the invention can be expressed in simplified form as equation (9).

$$T_i(U) = T_{F_i} + \gamma_i (B - U) \tag{9}$$

As shown in equation (9), $T_i(U)$ is the threshold for the i^{th} connection buffer when the overall buffer usage is U. B is the total shared buffer size, and γ_i is 2^y where y is chosen for the

i^{th} connection at the time the connection is set-up based on service category and total shared buffer size. The thresholds, buffer size and buffer usage are given as an integer number of cells.

According to a preferred embodiment of the invention, minimum and maximum queue occupancy levels (Q_{min} and Q_{max}) are also set by the dynamic thresholding scheme for each connection. Table 1 illustrates the presently preferred recommended dynamic threshold parameters for five different service categories.

Service Category	y	T_F	Q_{max}	Q_{min}
CBR	$\lceil \log_2(\frac{\alpha}{4B}) \rceil$	$\tau_{PCR} \cdot PCR$	$\frac{T_p + 2^y B}{(1+2^y)}$	$\tau_{PCR} \cdot PCR$
VBR-rt	$\lceil \log_2(\frac{\alpha}{4B}) \rceil$	$\tau_{PCR} \cdot PCR$	$\frac{T_p + 2^y B}{(1+2^y)}$	$\tau_{PCR} \cdot PCR$
VBR-nrt	-4	b_e	$\frac{T_p + 2^{-4} B}{(1+2^{-4})}$	b_e
ABR	-4	TBE	$\frac{T_p + 2^{-4} B}{(1+2^{-4})}$	TBE
UBR	0	0	$\frac{B}{2}$	$\frac{B}{(1+N)}$

Table 1

In Table 1, α is a dimensionless coefficient as defined by ITU I.371, the complete disclosure of which is hereby incorporated herein by reference. The default value of α is 120. PCR refers to the peak cell rate and τ_{PCR} refers to the cell delay variation tolerance or CDVT as defined in ITU I.371 for constant bit rate (CBR) and variable bit rate-real time (VBR-rt) service categories. As above, B is the size of the shared buffer in number of cells. b_e is the effective buffer size as defined in IEEE Journal on Selected Areas in Communications, Vol. 13, No. 6, pp. 1115-11127 (1995) and TBE is the transient buffer exposure as defined in ATM forum Traffic Management Specification 4.0, April 1996, #af-tm-0056.000. The minimum buffer size Q_{min} is the minimum size of the buffer in number of cells when the shared buffer is completely full. Q_{max} is the maximum queue occupancy (in number of cells) allowed for a particular connection. For unspecified bit rate (UBR) service, Q_{max} is purely a function of the total shared buffer size and Q_{min} is a function of total shared buffer size and number of backlogged connections N. For a given service category, the value of the y parameter should be chosen such that the resulting value of Q_{max} is greater than or equal to the maximum value of Q_{min} for the service category. Moreover, for a given service category, y should be set proportionally to the expected queue length of a connection in the category.

Several properties of the buffer management scheme can be ascertained from an analysis of the threshold formula shown in equation (9). For example, if there are N connections each having a queue threshold defined by T_{Fi} and γ_i, and if all connections are completely backlogged (i.e. their corresponding queue lengths are at their corresponding dynamic thresholds T_i ($i = 1, 2, 3, \ldots, N$)), then the steady-state vc threshold (or the queue length) for each connection i can be expressed as shown in equation (10).

$$T_i = Q_{vc_i} = \frac{T_{F_i} \cdot \left(1 + \sum_{k=1(k \neq i)}^{N} \gamma_k\right) + \gamma_i \cdot \left(B - \sum_{k=1(k \neq i)}^{N} T_{F_k}\right)}{\left(1 + \sum_{k=1}^{N}\right)} \quad (10)$$

The truth of equation (10) can be proven by iterative computation for N≥2. For example, where N=2, there will be two iterations of equation (9), one for i=1 and one for i=2. If the second equation is rewritten as a function of U as shown in equation (11), it can be substituted into the first equation to establish the relationship between the two thresholds as shown in equation (12).

$$U = \frac{(T_{F_2} - T_2)}{\gamma_2} + B \quad (11)$$

$$T_1 = T_{F_1} - \frac{\gamma_1}{\gamma_2} \cdot T_{F_2} + \frac{\gamma_1}{\gamma_2} \cdot T_2 \quad (12)$$

Under a complete backlog condition $U=T_1+T_2$ which can be used to rewrite the second iteration of equation (9), i.e. where $i=2$, as equation (13).

$$T_2 = T_{F_2} + \gamma_2 B - \gamma_2 T_1 - \gamma_2 T_2 \quad (13)$$

Substituting equation (12) in equation (13) yields equation (14) which is exemplary of equation (10).

$$T_2 = \frac{T_{F_2} \cdot (1+\gamma_1) + \gamma_2 \cdot (B - T_{F_1})}{(1+\gamma_1+\gamma_2)} \quad (14)$$

Similarly, if the expression for T_2 from equation (14) is substituted in equation (12), equation (15) is produced which is also exemplary of equation (10).

$$T_1 = \frac{T_{F_1} \cdot (1+\gamma_2) + \gamma_1 \cdot (B - T_{F_2})}{(1+\gamma_1+\gamma_2)} \quad (15)$$

Repeating this process iteratively for higher values of N, will establish the truth of equation (10).

A first corollary to the proof of equation (10) is that if there are N backlogged connections, each with the same γ_i but with different T_{Fi}, then their steady-state queue lengths will be given by equation (16).

$$T_i = Q_{wc_i} = \frac{T_{F_i}(1+(N-1)\gamma) + \gamma\left(B - \sum_{k=1(k\neq i)}^{N} T_{F_k}\right)}{(1+N\gamma)} \quad (16)$$

A second corollary to the proof of equation (10) is that if there are N backlogged connections with the same γ_i and with the same T_{Fi}, then their steady-state queue lengths will be given by equation (17).

$$T_i = Q_{wc_i} = \frac{T_F + \gamma B}{(1+N\gamma)} \quad (17)$$

The analytical results of equations (10), (16), and (17) were compared with simulation results obtained by simulating three connections sharing a common memory pool. The simulation

memory was partitioned into per connection logical queues. Complete backlogged conditions were created by having per connection input rates exceed the output rates. A comparison of the simulation results with the analytical results is illustrated in Table 2.

Number of Connections	Connection Parameters (B=1,000 cells)			Queue Lengths via Analytical Results			Queue Lengths via Simulations		
	γ_1, T_{F1}	γ_2, T_{F2}	γ_3, T_{F3}	Q_1 cells	Q_2 cells	Q_3 cells	Q_1 cells	Q_2 cells	Q_3 cells
1	1,10	-	-	505	-	-	504	-	-
2	1,10	2,15	-	253.7	502.5	-	254	502	-
3	1,10	2,15	4,20	129.3	253.7	497.5	128	254	498
3	1,10	1,20	1,30	245	255	265	244	256	264

Table 2

As can be seen in Table 2, the analytical results and the simulation results are virtually identical. The small differences between the results are because the simulation results were truncated to the nearest integer.

Those skilled in the art will appreciate that the dynamic buffer management scheme may be implemented in a combination of hardware and software in order to perform the functions outlined above. Referring now to Figure 2, an apparatus according to the invention will determine at 10 when a new virtual connection is about to be established. If a new VC is being established, the apparatus will determine at 12 the service category of the new VC and will set the parameters based on the service category at 14. These parameters include T_F, γ, Q_{max}, and Q_{min}. At 16, the apparatus will determine the amount of free space in the shared buffer and at 18 the apparatus will set the dynamic queue threshold using equation (9). The apparatus will return to step

10. When no new VC is being established the apparatus will continue to monitor the amount of free space in the shared buffer at 16 and will reset the dynamic queue thresholds at 18 accordingly. Based on the queue thresholds, determination may be made by the apparatus to discard cells which would cause the queue length to exceed the queue threshold.

There have been described and illustrated herein several embodiments of a dynamic buffer management scheme for ATM switched. While particular embodiments of the invention have been described, it is not intended that the invention be limited thereto, as it is intended that the invention be as broad in scope as the art will allow and that the specification be read likewise. It will therefore be appreciated by those skilled in the art that yet other modifications could be made to the provided invention without deviating from its spirit and scope as so claimed.

Claims:

1. A dynamic buffer management method for managing multiple ATM queues in a shared buffer, comprising:

a) creating a queue for each virtual connection at the time the virtual connection is set up;

b) setting a minimum queue threshold for each queue at the time it is created based on the service category of the virtual connection for which the queue was created;

c) dynamically adjusting the queue threshold for each queue based on the minimum queue threshold and the amount of unused shared buffer space.

2. A method according to claim 1, wherein:

said step of adjusting includes increasing the minimum queue threshold by a fractional amount of the unused shared buffer space.

3. A method according to claim 2, wherein:

the fractional amount which is added to the minimum queue threshold is determined by the service category of the virtual connection for which the queue was created.

4. A method according to claim 1, further comprising:

d) setting a maximum permitted queue occupancy for each queue at the time it is created based on the service category of the virtual connection for which the queue was created.

5. A method according to claim 4, wherein:

the maximum permitted queue occupancy is a fractional amount of the dynamically adjusted queue threshold when the buffer is empty.

6. A method according to claim 4, further comprising:

e) setting a minimum queue occupancy for each queue at the time it is created based on the service category of the virtual connection for which the queue was created.

7. A method according to claim 6, wherein:

the minimum queue occupancy is based on the number of active backlogged connections.

8. A dynamic buffer management method for managing multiple ATM queues in a shared buffer, comprising:

a) creating a queue for each virtual connection at the time the virtual connection is set up;

b) setting a minimum queue threshold T_{Fi} for each i^{th} queue at the time it is created based on the service category of the virtual connection for which the queue was created;

c) dynamically adjusting the queue threshold for each queue based on the formula

$$T_i(U) = T_{F_i} + \gamma_i \cdot (B - U)$$

where B is the total size of the shared buffer, U is the size of the currently used portion of the buffer, γ_i is a fraction based on the service category of the virtual connection for which the queue was created, and $T_i(U)$ is the dynamically adjusted threshold (in number of cells) for the i^{th} connection when the used portion of the buffer is U.

9. A method according to claim 8, wherein:

$\gamma_i = 2^y$ where y is chosen based on the service category of the connection.

10. A method according to claim 9, further comprising:

d) setting a maximum permitted queue occupancy Q_{max} for each queue at the time it is created based on the formula

$$Q_{max} = \frac{T_F + 2^y B}{(1 + 2^y)}$$

11. A method according to claim 10, wherein:
for CBR service and for VBR-rt service $y = \lceil \log_2 \frac{\alpha}{4B} \rceil$ and $T_F = \tau_{PCR} \cdot PCR$;
for VBR-nrt service y=-4 and $T_F=b_e$.
for ABR service y=-4 and $T_F=TBE$; and
for UBR service y=0 and $T_F=0$.

12. An apparatus for dynamically managing multiple ATM queues in a shared buffer, comprising:
a) means for creating a queue for each virtual connection at the time the virtual connection is set up;
b) means of setting a minimum queue threshold for each queue at the time it is created based on the service category of the virtual connection for which the queue was created;
c) means for dynamically adjusting the queue threshold for each queue based on the minimum queue threshold and the amount of unused shared buffer space.

13. An apparatus according to claim 12, wherein:
said means for dynamically adjusting includes means for increasing the minimum queue threshold by a fractional amount of the unused shared buffer space.

14. An apparatus according to claim 13, wherein:
said means for dynamically adjusting includes means for determining the fractional amount which is added to the minimum queue threshold based upon the service category of the virtual connection for which the queue was created.

15. An apparatus according to claim 12, further comprising:
d) means for setting a maximum permitted queue occupancy for each queue at the time it is created based on the service category of the virtual connection for which the queue was created.

16. An apparatus according to claim 15, further comprising:

e) means for setting a minimum queue occupancy for each queue at the time it is created based on the service category of the virtual connection for which the queue was created.

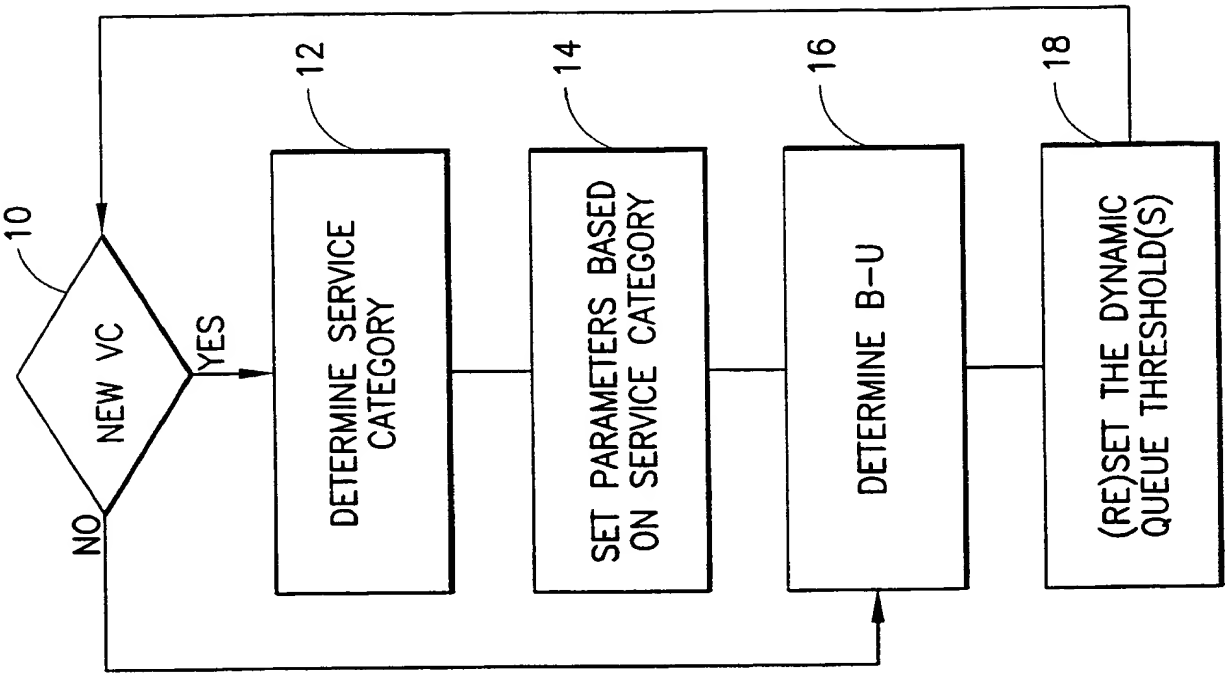
10
NEW VC
YES
NO
12
DETERMINE SERVICE CATEGORY
14
SET PARAMETERS BASED ON SERVICE CATEGORY
16
DETERMINE B-U
18
(RE)SET THE DYNAMIC QUEUE THRESHOLD(S)

FIG.2

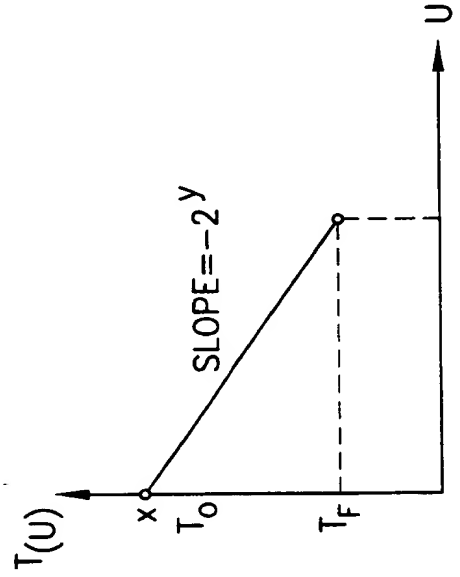
U
SLOPE=-2^y
$T_{(U)}$
x
T_O
T_F

FIG.1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/16477

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : G06F 13/14
US CL : 370/17, 60.1, 61, 232, 253

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 370/17, 60.1, 61, 232, 253

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,541,912 A (CHOUDHURY et al) 30 JULY 1996, COL. 1, LINES 56-67, COL. 4, LINES 21-37, COL. 5, LINES 1-67, COL. 6, LINES 1-67, COL. 7, LINES 1-67, COL. 8, LINES 1-67 & COL. 10. LINES 51-54.	1-16
Y, P	US 5,901,139 A (SHINOHARA) 04 MAY 1999, COL. 2, LINES 57-67, COL. 3, LINES 1-5, COL. 5, LINES 50-65, COL. 6, LINES 14-67, COL. 9, LINES 61-67 & COL. 10, LINES 1-67.	1-16

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search 12 SEPTEMBER 1999	Date of mailing of the international search report 04 OCT 1999
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